# Sustaining a Federation of Future Internet Experimental Facilities

***Jan Van Ooteghem*[1], *Steve Taylor*[2], *Paul Grace*[2], *Felicia Lobillo*[3], *Mikhail Smirnov*[4], *Piet Demeester*[1]***

[1] Ghent University – iMinds
Gaston Crommenlaan 8 bus 201
B-9050 Gent, Belgium

[2] IT Innovation Centre, Southampton, UK
[3] Atos, Madrid, Spain
[4] Fraunhofer FOKUS, Berlin, Germany

Corresponding author: jan.vanooteghem@intec.ugent.be

## Abstract

The growing complexity of the Future Internet landscape has driven the need for large-scale federations of experimental testbeds that support the next generation of research and experimentation. However, such facilities are typically difficult to sustain in the long term, particularly in the transition from a publically funded development to a self-sustaining operation. Fed4FIRE is a cross-domain federation of Future Internet testbeds that seeks to lower the barrier to complex experimentation. This paper explores the Fed4FIRE sustainability plan in further detail, and first documents how our value proposition was elicited from key stakeholder requirement analysis. We examine and analyse further the potential service portfolio to be offered and operated by the federator, making use of a service management approach, and how this applies to the viability of potential federation business scenarios and their impact on all involved stakeholders in the long term. A plausible scenario is then proposed and evaluated. Finally we present some conclusions.

*Keywords:* Sustainability, Value proposition, Federation, Experimentation, FIRE

# 1. Introduction

The Future Internet landscape is becoming increasingly complex: large-scale data systems and cloud computing services, highly heterogeneous Internet of Things technologies including sensor networks and smart mobile devices, new wireless and networking technologies (such as software defined networks). Hence, performing research and experimentation in this domain has become challenging; there is a growing need to lower the barrier for performing experiments with innovating novel technologies and based on new business models.

Within the EC-funded landscape, there are a large number of individual experimental testbeds, each with their own service offering (e.g. infrastructure, platform, software, knowledge). The FIRE initiative (Future Internet Research and Experimentation) [1] contains a number of these cutting-edge facilities. For experimenters, this landscape is disperse and difficult to grasp. For testbeds, a number of challenges to sustain their operation in the long term (in terms of funding, adoption of experimentation, operations, etc.) have to be faced. Therefore, in order to enable experimenters and testbeds to easily work together for mutual benefit, federations of testbeds have been set up, focused mainly per domain: cloud (BonFIRE [2] and Helix Nebula [3]), wireless networking testbeds (e.g. CREW [4]), and software defined networking (e.g. OFELIA [5]). A federation of testbed facilities can be seen as a collection of multiple independent testbeds that can be coordinated in different ways for the creation of rich, multi-functional environments for testing and experimentation; and has clear benefits for its main stakeholders - experimenters and facility providers.

With the growing demand for ever more complex Future Internet systems and experiments, there is a strong requirement to sustain federated cross-domain experimental facilities: i) to ensure the latest cutting-edge facilities are available to a large and experienced set of established communities; ii) to offer centralized services and minimize operational costs; and iii) continually generate value and impact beyond the original funding. In this paper, we explore how to sustain such a federation of experimental facilities in order to serve the needs of experimenters and testbeds in the future of the Internet. We present the EC FP7 Fed4FIRE project [6] whose objective is to create a common framework for the federation of FIRE facilities across Europe.

In this paper, we present the sustainability plan for the federation beyond the lifetime of the project. We will focus on the following key contributions:

- *Identification of the value proposition*. We describe how we identified the value proposition of Fed4FIRE and how this impacts on the continuing and changing needs of experimental users and testbeds. And, in turn, how long term sustainability must plan for such changes.
- *What is the service offering*? Services provided by the federation come with a cost; such costs add to the challenge of sustainability. We observe what are the key services that are required in the long term and examine the appropriate federation and business models that underpin their delivery.
- *Finding the appropriate business scenario.* Based upon the requirements from testbeds and experimenters we make a selection of the most suited service components fit and calculate the costs and benefits for facilitator and testbed.

We end this paper with initial conclusions and next steps.

## 2. Sustaining Fed4FIRE: an overall approach

Sustainability can be considered as the ability to continue. This should be guaranteed on a technical, economic and operational level. First an overview is given on the purpose of the Fed4FIRE project. Next, we present the main stakeholders. A clear value proposition must be presented in order to attract them and keep them interested in participating in the federation and using the services offered. We conclude this section on how we will proceed with this analysis.

### 2.1 Introduction to Fed4FIRE

Experimentally driven research is considered to be a key factor for growing the European Internet industry. In order to enable these types of RTD activities, a number of projects for building a European facility for Future Internet Research and Experimentation (FIRE) have been launched; each project targeting a specific community within the Future Internet ecosystem. Through the federation of these infrastructures, innovative experiments that break the boundaries of these domains become possible. Recent projects have already successfully demonstrated the advantages of federation within a community. The Fed4FIRE project implements the next step by successfully federating across the community borders and offering openness for future extensions.

Fed4FIRE establishes a common federation framework by developing, adapting or adopting tools that support experiment lifecycle management, monitoring and trustworthiness. A large number of existing experimentation facilities in Europe are being adapted to seamlessly integrate into the federation. Such facilities typically focus on different kinds of networking related research or on different communities regarding services and applications. Example domains are optical networking, wireless networking, software defined networking, cloud computing, grid computing and smart cities.

Fed4FIRE enables large-scale multi-technology experimentation by providing common tools to these facilities, which are offered to and used by experimenters as if they were only one (on the most extreme case of centralization), as presented in Figure 1. For example, thanks to Fed4FIRE, a testbed based on wireless sensors and another one based on cloud technology, each operated by an independent provider, can be combined in the same experiment (for example, to process sensor measurements retrieved from the wireless sensor testbed over the cloud facility in order to validate a new cloud-based IoT application).

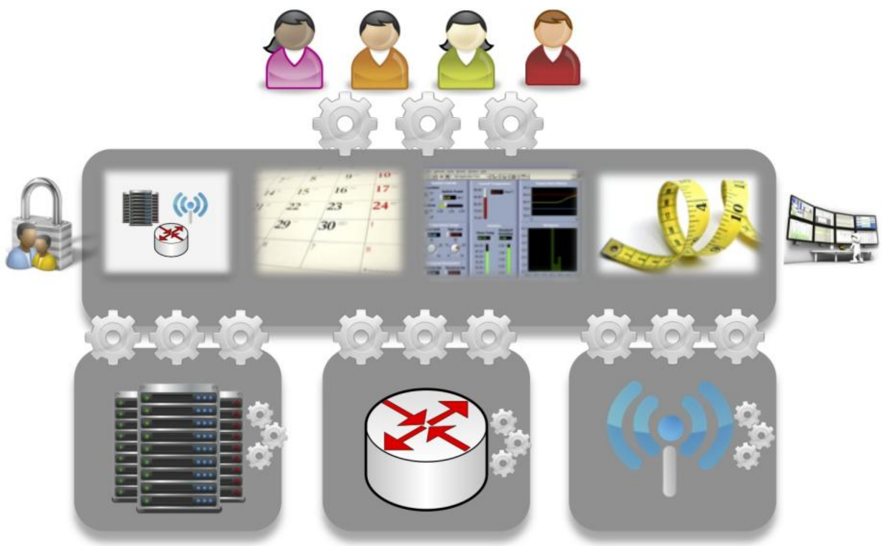

**Figure 1: Fed4FIRE facility: overall approach**

To summarize Fed4FIRE: "A federation of testbed facilities is a collection of multiple independent testbeds that can be coordinated in different ways for the creation of rich, multi-functional environments for testing and experimentation; and has clear benefits for its main stakeholders - experimenters, and facility providers." [7]

## 2.2 Stakeholder analysis

Before defining the business scenarios and analysing their value networks, the exercise of identifying the stakeholders involved and their relationships is required. Within this project, we define a stakeholder as "any entity whose activity is currently or potentially related to the federation in a direct or indirect manner and, as such, can derive benefits from the existence of such a federation (with or without cost)".

Figure 2 depicts an overview of the Fed4FIRE landscape in terms of roles. There are three main stakeholder types in Fed4FIRE. These are classed as the main ones because they are the primary participants in a federation – it would be difficult (though not impossible) for a federation to operate without all of these three stakeholder types. We will thus focus on the relationship between federator, experimenter and facility providers (testbeds) within this paper. The other stakeholders will not be discussed.

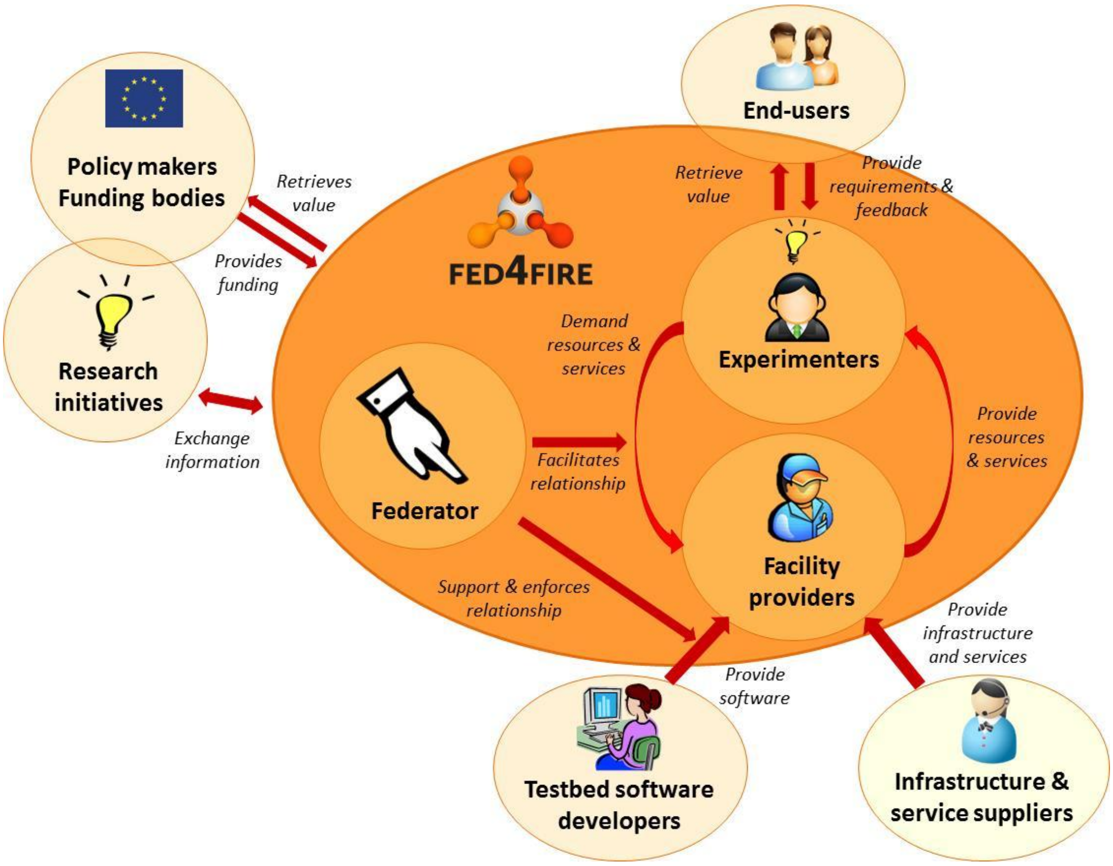


**Figure 2: Fed4FIRE landscape**

### 2.2.1 Experimenter

Experimenters are the players that want to use the Future Internet (FI) experimentation facilities for their research and development work. They have a demand for experimentation resources for different objectives (academic, industrial, partnerships).

The main benefit Fed4FIRE brings for experimenters is the ability to experiment. This is already provided by the testbeds, but a federation of testbeds provides much greater scope and flexibility for the experimenter: the federation of heterogeneous facilities brings the possibility to carry out large-scale experiments in a multi-technology and multi-vendor environment. Moreover, experimenters can benefit from services offered by the federation, such as operational support and SLA guarantees.

### 2.2.2 Facility provider

These are the owners, operators and maintainers of experimentation facilities who offer testbed services and experimentation resources to experimenters.

Facilities bringing their resources to the federation; these can be individual testbeds and also facilities that group several testbeds assembled and operating under a common framework. In the latter case, the facility would be a federated entity joining a higher level federation. It can also happen that within this federated facility, only some of the testbeds are represented in the future federation. This is the case of BonFIRE, for example, in Fed4FIRE.

The main benefits a federation brings to facility providers is the possibility to improve the attractiveness to the facility by embedding it into a broader community (e.g. by the use of common interfaces and best practices), increasing the usage of the facility and enhancing its reputation. Infrastructure providers can also have access to a range of common tools, frameworks and libraries that reduce operational costs in terms of maintenance and improvements of the facility. Moreover, service level agreements (SLAs) may help facility providers protect their infrastructure against potential abuse, misuse or damages introduced by experimenters by establishing a trust framework including rights and obligations of all parties involved in an experiment.

### 2.2.3 Federator

The federator is a body who enables federation to happen between the other stakeholders, i.e. to enable them to communicate, understand each other and cooperate with each other for mutual benefit. The federator may have a number of different functions (these are dependent on the business scenario), but all the federator’s functions contribute to the goal of enabling federation.

The federator is distinct from the other two main stakeholders, the experimenter and the facility provider. The experimenter behaves as a consumer, and a facility provider behaves as a supplier, and the federator enables them to talk to each other and others of their kind.

The federator might also play the role of business facilitator and foster relationships within a broader reach of facility providers and experimenters by bringing market knowledge allowing better business opportunities.

We have asserted that sustainability work in Fed4FIRE incorporates the role of the federator. The federator enables the federation to operate, and the federator’s survival depends on successful operation of the federation. To achieve this, not only must the federator make it possible for the federation to operate, it must also determine clear benefits / value for the other main stakeholders.

## 2.3 The Fed4FIRE sustainability approach

Sustainability can be considered as the *ability to continue*. Sustaining a federation of experimental testbed facilities is driven by three important factors:

- *Sustainable need:* there is an ongoing need for someone to use the federation to compose experiments across heterogeneous experimental facilities. Once the need disappears then there is no need to continue providing the service. An important consideration is that market needs change over time; this is especially relevant to research-based facilities where the need for today's hot technology dies once innovation is saturated. Hence sustainable need must consider changing customer needs, and may change its service accordingly.

- *Sustainable capability:* the continued provision of a service, i.e., generating the required resources (e.g. money) to maintain operation of the federation. Long-term sustainability plans typically focus on minimizing direct costs and developing diverse and reliable revenue streams [7]. Experimental facilities that wish to sustain beyond the initial project funding (e.g. a European Commission Capacity building project) must examine future customer relationships and be creative in seeking alternative revenue streams. For example, open source software projects generally migrate from a project model to a service model (e.g. consultancy and support for the use of free software) on top of which commercial relationships can be built [8].
- *Sustainable community:* a set of people who are willing to donate their time and skills in order to add value to the federation. This can be in terms of bug identification, suggesting new requirements and features, testing, project management and traditional software development practices.

Sustainability plans generally focus on capability; however, [7] identifies that "it is not about the money; it's not about getting by; **it is about identifying value to a specific group or stakeholder**". Similarly, [8] states that "continuity of effort and requirement/need is fundamental". Sustainable need and capability are strongly coupled and hence **value is the capability that answers a sustainable need**. This is further identified in [7] where a clear value proposition offers something unique, of need and continues to add value based on changing user demands.

Note well that Fed4FIRE does not directly tackle the sustainability of individual testbeds; however, the sustainability of the federation could of course have an impact on the sustainability of each facility. The previous principles drive Fed4FIRE's approach to the sustainability of the federation. The federation offers a set of key services that meet the desired value proposition. We chose an IT service management approach to deliver these services because Fed4FIRE is building a federation based on IT solutions. Moreover, IT service management is a recognized solution for the delivery of high quality IT services that meet the demands and expectations of users. After all, Fed4FIRE will deliver services that rely on IT solutions thus it is very convenient to define the procedures required to carry out these services. Hence, the management of service components is underpinned by business models that optimize their delivery (through procedures), and hence lead to a more sustainable capability.

In the following sections we examine the individual elements of the sustainability plan in greater detail, namely: i) the value proposition, ii) the service model, and iii) the business scenarios.

# 3. The Fed4FIRE Value proposition

**Methodology**. To identify the value proposition we leveraged information obtained from open call submissions to help us identify what experimenters and testbeds saw the value of Fed4FIRE to be. Here, Fed4FIRE operated an open call where new testbed facilities and experimenters could seek funds to either join the federation or use the facilities; within the proposals we found very valuable insights concerning their expectations in terms of what value they thought they would gain from collaboration with Fed4FIRE. We analysed this information and highlighted the common value statements, and also those where it was clear significant value was provided.

**Results**. Fed4FIRE uniquely provides the ability to combine multiple distributed, heterogeneous testbeds to support Future Internet experimenters. A future operator of Fed4FIRE (the federator) is ***not*** an experimenter or a testbed: instead, it is an organization that *enables* federation to happen - an organization that mediates between experimenters and testbeds and enables experimenters and testbeds to join together for the benefit of both. Fed4FIRE goes beyond single-function federations of testbeds. The diverse collection of testbeds in Fed4FIRE, and the potential to allow others of different types to join (and leave) in the future offers a novel and desirable platform for experimenters to utilize and testbeds to be a part of.

In terms of a future Fed4FIRE value proposition, we think it is important to have two related value propositions, each one targeting a different type of stakeholder:

- a value proposition targeted at the experimenters;
- a value proposition targeted at the testbeds.

The experimenters and testbeds are the two key stakeholder types that Fed4FIRE is concerned with, and ***both*** are needed for Fed4FIRE to work and continue into the future! Our current thinking is that a significant part of Fed4FIRE's two value propositions is concerned with enabling experimenters and testbeds to work together with each other. We assert that the two value propositions should be compatible and consistent. If this is not the case, the operation of Fed4FIRE may be made difficult or impossible.

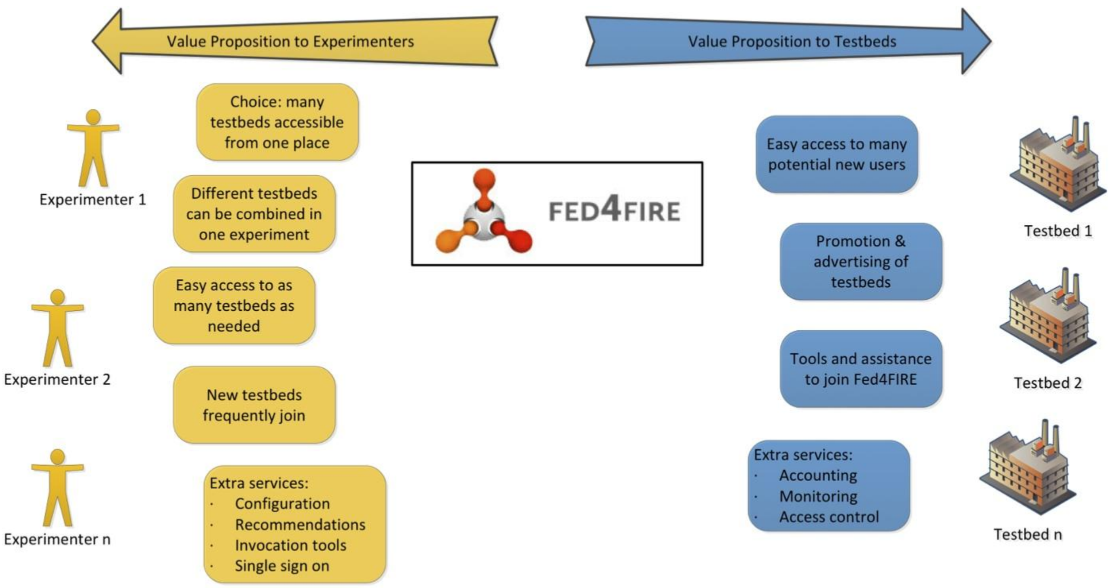


**Figure 3: Value Propositions of Fed4FIRE to Testbeds and Experimenters**

Figure 3 illustrates this compatible and consistent proposition delivered by Fed4FIRE. The blue and orange boxes in the picture are examples of benefits to the experimenters and testbeds, i.e. the value proposition of Fed4FIRE to each stakeholder type. These are examples, with the intention of illustrating that there are separate benefits to the experimenters and testbeds, and that both stakeholder types are needed for the federation to work. It is not known if all of the example value propositions above are possible and others are also likely to be applicable, but the key point is that Fed4FIRE should offer significant value to both experimenters and testbeds in order to be sustainable. Hopefully it is clear from the above that Fed4FIRE, being able to mediate between experimenters and testbeds, will bring benefits for all.

## 3.1 Experimenters

Figure 3 highlights the value available to experimenters. This also demonstrates the important concept that it is the federator and the testbeds in combination that add value for the experimenters. The most important are choice of testbeds, combination of testbeds and easy access. Hence, Fed4FIRE allows experimental functionality to be flexibly created by the user, for example:

- An experimenter can pick and choose which testbeds to combine.
- An experimenter can select facilities based upon location or other non-functional requirements.
- The combination of testbeds generates new experimental testbed functionality.
- Functionality can be quickly configured, which would be expensive and time-consuming for an experimenter to replicate the experiments themselves.

A key question regarding the sustainability of Fed4FIRE is the extent to which there is a *sustainable need*. That is, once the exercise of federating testbeds is complete and the value proposition is fully realized is there a market of users who will benefit from the offering and more importantly will this *need* sustain in the long term?

At present and until the end of the Fed4FIRE project, Fed4FIRE users (customers) can be broken down into two categories:

- Members of the Fed4FIRE consortium who use Fed4FIRE as a demonstrator for their work within the project.
- Potential users of Fed4FIRE via the open call funding mechanism. These users have expressed interest in building cross facility experiments in order to win funding. In the initial open call 55 proposals were submitted.

The open call clearly shows there is interest in Fed4FIRE although this remains a small market size, and it is difficult to assess whether this is driven by experimenter demand or by funding push (i.e. they are paid to leverage Fed4FIRE). In order to be sustainable, Fed4FIRE must go beyond these parameters and target a wider market audience.

The FIRE user base can be broadly split into four user types:

1. *Experimental computer scientists*. Academics whose general goal is to produce novel innovations in the field of computer science, typically through the development of new systems, software, protocols, etc. They validate their hypothesis using experimental methods rather than the proofs employed by theoretical computer scientists. The expected outcome is a publication in a high-impact venue (e.g. conference or journal); a small proportion of these computer scientists will seek to transfer their innovation to a commercial product or service.
2. *Technology innovator*. Hobbyist, hacker, social do-gooder, and innovator are some of the tags given to people who explore how new technology can be applied.

Whether this is for an intellectual challenge or for community good (other people can build upon the work c.f. open source initiatives) the work can often be a springboard for commercial uptake or for wider social impact.

3. *Commercial R&D engineers (start-ups, SMEs, industry)*. Commercial R&D is typically expensive with a high risk of no return. Hence, there is pressing need to offer low cost, low barrier entry facilities in order for commercial engineers to quickly assess the viability of an innovation before committing further resources.
4. *Educators*. There is a need to educate tomorrow's technologists in Future Internet technologies and hence students and educators can leverage the FIRE facilities to perform training exercises to understand both technologies and concepts. Such educators will be university professors teaching undergraduate, masters and Ph.D. students. PlanetLab [11] has consistently been used to educate graduate students. The trend towards Massive Open Online Courses also offers an interesting channel for educating the next generation of users.

In the short term, experimental computer scientists, researchers and educators are clearly the most relevant users of the Fed4FIRE facility (cf. Fed4FIRE consortium and experiment proposers in the open call). Does Fed4FIRE meet their needs? Does Fed4FIRE provide value to attract more of these users?

## 3.2 Facility providers

Figure 3 also highlights the value available to testbeds; again this is created by the combination of the federation with a stakeholder (in this case experimenters):

- *Greater potential market for testbeds*. Fed4FIRE has an existing customer base that a testbed can target once joining the federation.
- *Advertising and promotion.* There are channels for each testbed to advertise and promote their service to the Fed4FIRE users.
- *One stop shop*. Their testbed can be composed with other testbeds to broaden the service offering and increasing the potential user base.
- Easy for new testbeds to *join the federation*; (very important to get new testbeds to keep the value up)
- *Common additional services*; reusable services like accounting, monitoring, access control, and invocation tools support standard integration of testbeds and also provide added value services on joining.

Following on from the *sustainable need* of experimenters; is there a sustainable need for testbeds to gain value from the federation? This is naturally tied to the needs of the users; where users require federation of testbeds there will be a market of users that can be targeted by the testbeds.

At present and until the end of the Fed4FIRE project, Fed4FIRE testbeds can be broken down into two categories:

- Existing federation testbeds: 17 testbeds joined from the initial Fed4FIRE federation and the extension after the first open call.
- Potential federation testbeds: during the project several open calls for testbeds have been conducted, with large amount of submissions. Up to now, 190 testbeds are registered in XIPI [10], an on-line catalogue of Future Internet infrastructures, which indicates the large potential testbed base. Besides, in Horizon 2020 new testbeds will continue to be funded (in the first work programme 2014-2015 there will be two new experimental facilities with one targeted to experiment-as-a-service)[12].

Therefore, Fed4FIRE’s current market share of European testbeds is low but there is significant potential for growth in order to sustain the need for the federation. Fed4FIRE also has the opportunity to monitor trends in order to spot gaps in the market and make proposals for new testbeds to join the federation based upon the needs of experimenters.

## 3.3 A changing value proposition

The value proposition is closely linked to the continuing needs of the user community. Anticipating the needs of the research community is a difficult task; however, research trends show that Fed4FIRE’s value proposition of composable heterogeneous testbeds is highly relevant for today’s researchers. The move towards smart cyber-physical systems, the Internet of People, and the Internet of Things means that heterogeneous devices are connected by a wide range of networking technologies. Data is consumed and produced and analysed at increasing scale—there are many challenges to address here and hence it can be observed that cloud testbeds, networking testbeds, sensor testbeds and other types of testbeds must be combined in order to support experiments with new technologies in these domains.

A key point of Fed4FIRE’s value proposition is that new testbeds can join the federation, so the federation can adapt to changing needs. The users are in charge of the combination of testbeds that meet their needs, and new testbeds joining the federation means users have greater choice. As new needs emerge, testbeds can be created to serve these needs and can be integrated into the federation. This offers a unique value proposition in comparison to a single integrated facility (i.e. one combination) and it is this property that allows the value proposition to be tailored to changing demands—new facilities can join the federation offering the latest experimental facilities. In order to address this aspect of the value proposition, a key requirement is that the federation must provide services or tooling to make it easy for new testbeds to join the federation.

Fed4fire directly supports changing value due to the value proposition of being a delivery channel for experimental facilities with a low entry barrier for new facilities and services.

# 4. The Service Management Model

We chose an IT service management approach within the project as Fed4FIRE is building a federation based on IT solutions. Moreover, IT service management is a recognized solution for the delivery of high quality IT services that meet the demands and expectations of users. After all, Fed4FIRE will deliver services that rely on IT solutions thus it is very convenient to define the procedures required to carry out these services.

We therefore adopt the FitSM model [13], a lightweight standards family aimed at facilitating service management in IT service provision, including federated scenarios. This is produced by the FedSM project [16], an initiative co-funded by the European Commission Seventh Framework Programme to improve service management in a select set of federated ICT infrastructures and bring experience from this improvement to a broad community of (federated) communities.

We adopted their vocabulary and templates to define a service, service component and configuration items.

- A *service* is defined as a way to provide value to a user/*customer* through bringing about results that they want to achieve.
- A service is composed of *service components* (SC), which are technical or non-technical elements helping to make up a service. It is any component, which underlies a service, but does not create value for a customer/user alone and is therefore not a service by itself.
- *Configuration items* (CI) are elements that contribute to the delivery of one or more services or service components, and therefore needs to be controlled. CIs vary widely and can be anything from technical components (switches, cables, software), effort (human resources) to documents (SLAs, contracts, procedures).

In the next sections, we will go deeper into the different core and supplementary services offered by the federation, their service components and configuration items.

## 4.1 Services in Fed4FIRE

Services are categorized based on two criteria: the user of the service (experimenters and experimentation facilities) and the importance of the service (core and supplementary services). Core services are considered as an expected amenity by the end users. Additional or supplementary services are considered as nice to have.

The federation focuses on the provisioning of the core services but could also implement certain supplementary services. It is key to grasp the benefits of a service and to understand how the provisioning of a service will contribute to the cost of a running federation. Some services may have a large benefit but only cost a little to provision while for others the opposite may be true.

The goal of the next section is to identify, classify and describe the possible services and to identify their components and configurable items in order to define the Fed4FIRE portfolio. This analysis started from the currently proposed and implemented architecture [14][15].

Table 1 gathers the list of core and supplementary services offered by the federation. All of these services rely on specific service components, which are described in the following section.

**Table 1: Core and supplementary services offered by the federation**

| | |
|---|---|
| Core service | **The ability to experiment across experimentation facilities**<br>The federation of heterogeneous facilities brings the possibility to carry out large scale experiments in a multi-technology and multi-vendor environment. |
| Supplementary services | **Experimenter training**<br>The federation offers experimenter training sessions and general support for setting up an experiment. The federation will thereby increase awareness and reduce the effort and time required to run experiments and reduce the risk of failure due to misconfiguration of facilities. |
| | **Shared support services**<br>The federation offers experimenters a central contact point for experiment support to deal with experimenter problems and to help experimenters with designing experiments. These include providing help about services, providing information about facility capabilities, organizing administrative functions dealing with access rights, etc. |
| | **Permanent storage**<br>Storage of experiment related information beyond the experiment lifetime, such as experiment description, disk images and measurements |

## 4.2 Service components

This section described service components for core and supplementary services. Our core service is the ability to experiment across experimentation facilities. This can furthermore be split up in different main categories: i) resource discovery, specification, reservation and provisioning, ii) monitoring and measurements and iii) experiment control. The supplementary services consist of experimenter training, support and permanent storage.

### 4.2.1 Service components for core services

We start with the first steps within the experiment lifecycle, namely the authentication (the processes for establishing roots of trust and issuing identities within a federation) and authorization (capabilities to protect access to data and other resources), resource description and discovery (finding the resources and applications), resource reservation (allocation) and provisioning (instantiation). Table 2 presents a more elaborate explanation.

**Table 2: Experiment lifecycle: resource discovery, specification, reservation and provisioning**

| | |
|---|---|
| Authentication and authorization | Authentication includes the processes for establishing roots of trust and issuing identities within a federation. Authorization includes the capabilities to protect access to data and other resources for only authorized individual including mechanisms for delegation and revocation of rights to experimenters and services operated within an organization of 3rd party organizations. |
| Resource description and discovery | Finding available resources and applications across all testbeds, and acquiring the necessary information to match required specifications, including the guarantees offered by the provider in terms of how the service will be delivered (e.g. availability of resources). Resource discovery can also provide information concerning the reputation of the facilities (trust) |

| | |
|---|---|
| Resource reservation | Allocation of a time slot in which exclusive access and control of particular resources is granted. |
| Resource provisioning | Instantiation of specific resources directly through the testbed API, responsibility of the experimenter to select individual resources. |

Two types of monitoring are considered: facility (supervise the behaviour and performance of the testbeds) and infrastructure (collecting data by the testbed itself on the behaviour and performance of services, technologies, and protocols). Experimenters want to monitor whether the service delivered to them is according to the agreed SLAs. Experimental data can also be collected for further evaluation. More details can be found in Table 3.

**Table 3: Experiment lifecycle: monitoring and measurement**

| | | |
|---|---|---|
| Monitoring | Facility monitoring | Instrumentation of resources to supervise the behaviour and performance of testbeds, allowing system administrators or first level support operators to verify that testbeds are performing correctly. |
| | Infrastructure monitoring | Instrumentation by the testbed itself of resources to collect data on the behaviour and performance of services, technologies, and protocols. This allows the experimenter to obtain monitoring information about the used resources that the experimenter could not collect himself. An example of such infrastructure monitoring is the provisioning by the testbed of information regarding the CPU load and NIC congestion on the physical host of a virtual machine resource. The experimenter can only collect monitoring data on the level of the VM, but the testbed provides infrastructure monitoring capabilities that make this data available to the experimenter. |
| Measuring | Experiment measuring | Collection of experimental data generated by frameworks or services that the experimenter can deploy on its own. |
| SLA evaluation | | Experimenters can also monitor the service delivered to them vs. expectations gathered in a service level agreement between providers and himself. |

Experiment control deals with control of the testbed resources and experimenter scripts during experiment execution (Table 4).

**Table 4: Experiment lifecycle: experiment control**

| | |
|---|---|
| Experiment control | Control of the testbed resources and experimenter scripts during experiment execution. This could be predefined interactions and commands to be executed on resources (events at start-up or during experiment workflow). Examples are: start-up or shutdown of compute nodes, change in wireless transmission frequency, instantiation of software components during the experiment and breaking a link at a certain time in the experiment. Real-time interactions that depend on unpredictable events during the execution of the experiment are also considered. |

### 4.2.2 Service components for supplementary services:

For supplementary services the main service components are training for experimenters, first level support (dealing with interactions with experimenters) and documentation about the elements of the federation; and storage systems and mechanisms to store experiment related information (Table 5 and Table 6).

**Table 5: Supplementary services: training and support**

| | |
|---|---|
| Training | Allows experimenters to contact the federation for training requests according to their needs |
| First Level Support | Interaction with customers for support request, incident communication, consultation, etc. |
| Documentation | Keeping up-to-date and rigorous documentation concerning the elements of the federation (user manuals, installation guides, etc.) complements direct support |

**Table 6: Supplementary services: permanent storage**

| | |
|---|---|
| Permanent storage | Systems and mechanisms allowing experimenters store experiment related information beyond the experiment lifetime, such as experiment description, disk images and measurements. |

## 4.3 Configuration items

Configuration items are elements that contribute to the delivery of one or more services or service components. Examples can be manpower (effort by people for installing and operating the service component), hardware (e.g. servers, switches, cables, etc.) and software components (e.g. GUIs, standard APIs, software libraries, etc.), documentation (e.g. training material, manuals, procedures), etc.

In a first iteration, we have estimated for a number of service components the required configuration items. This is based on knowledge gained during the development and installation of the different components within the project. We made a distinction between federator and testbed dedicated costs, and general tool development, of which the latter can be done by either one or them, or an external party. We considered following resource categories: hardware and software components, support and content provisioning, split up between purchase, development, installation, updates and maintenance, of which the operational costs are expressed in required full time equivalents (FTE).

Different service component offerings are considered, as some components can be offered in a minimum up to an advanced setting (e.g. for first level support this can be a very basic website or forum, up to a full service call center functionality). This will be further elaborated in section 5.

# 5. Business scenarios

In the previous section we introduced the service management model we will follow within the project. This methodology and information will now be used for defining business scenarios with a specific service offering from federator point of view, considering of course the interaction with and potential benefits for the different testbeds, as shown in Figure 4. One specific case will be elaborated with an initial qualitatively and quantitative evaluation.

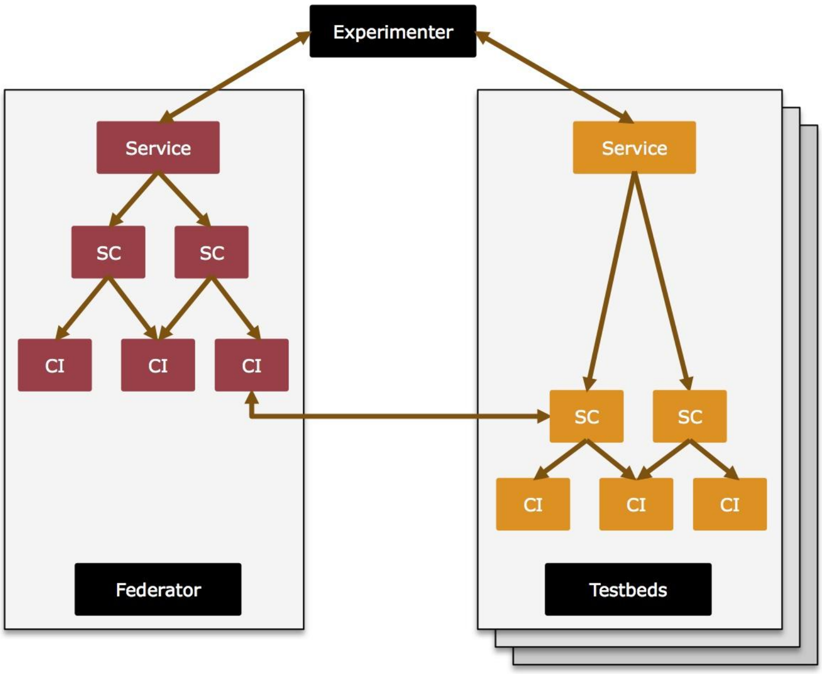


**Figure 4: Service management structure**

## 5.1 Federation scenarios

The FedSM project identifies a set of scenarios for the operation of federated IT facilities; these provide a useful analysis tool to consider how Fed4FIRE can be operated most effectively to optimize service delivery and minimize the federation's delivery costs [17]. Essentially these scenarios identify core services and determine whether they are provided in a coordinated manner by a central federator, or are delivered by each federation member (testbed) in an un-coordinated fashion. The spectrum of scenarios ranges from "Invisible coordinator" to "Integrator". In the Invisible coordinator scenario, the federator may provide functions like: i) Interaction & communication protocols, ii) APIs & interface specifications, iii) certification authority. All these enable the federation to take place, without the federator needing to get involved at runtime - the federation participants can use these functions to interact directly with each other. The primary value added by the federator is thus in the definition of the protocols and standards, and the other two stakeholders benefit by using them to understand how to cooperate together.

Integrator is the opposite of Invisible Co-ordination, where federator coordinates all of the services. A real-world analogy of this model is that of a prime (or general) contractor. The term comes from the construction industry and a prime contractor is the manager of a building project. The prime contractor bears full responsibility for the delivery of the completed project to the customer; the prime contractor is likely to employ subcontractors to carry out specialist tasks (e.g. building construction, plumbing, carpentry, electrical installation etc.); and the prime contractor is the sole party that deals with the customer. The benefit to the customer is that they have a single point of contact, who is responsible for managing a complex project. The customer also benefits through having one party who is responsible for the project as a whole. The subcontractors typically benefit through the promise of significant amounts of work (most managed building projects involve significant amounts of work for subcontractors). We can see that in the Integrator model, the prime contractor is the federator, and the subcontractors are the testbeds, so the benefits to the experimenters are similar to those of a prime contractor's customers – the experimenter gets a complete managed service for a possibly complex experiment involving many testbeds. The more complex the experiment is, the greater the benefit of the federator in this scenario, because it saves the experimenter significant work in the overheads of dealing with multiple testbeds.

## 5.2 Plausible federation scenario for Fed4FIRE

The federation scenarios are different ways that different stakeholders can interact to get useful value from their interaction in a federation. But which is the right scenario for Fed4FIRE? This role analysis method allows us to consider plausible operations; here we take each of the core services identified in the previous section and determine whether that service should be provided by the federator in a coordinated manner to the experimenter; or whether the service should be provided in an uncoordinated manner by the testbed direct to the experimenter. We need consider in the end whether the benefits still outrun the cost (Figure 5).

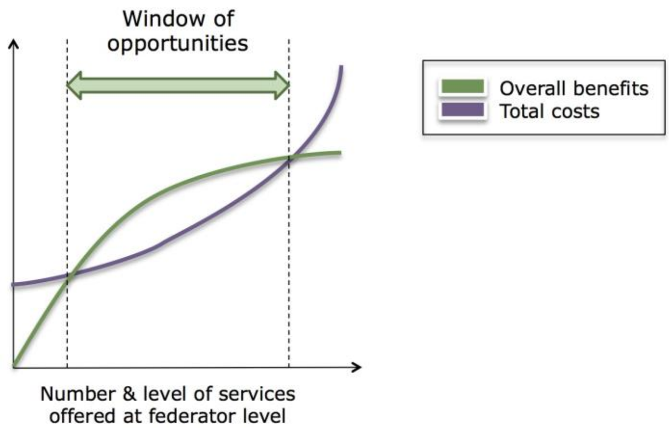


**Figure 5: Window of opportunity for the federator**

Table 7 identifies a plausible scenario for Fed4FIRE that is similar to the "one-stop-shop" FedSM scenario [17]. The federator provides all the support to find and acquire the right to use the facilities' resources e.g. discovery and reservation. Further, the experimenter invokes services on the infrastructures directly. Also, as with the "Matchmaker" scenario, the need for contracts or SLAs between the federator and the facility providers may be necessary, so as to determine what the federator can and cannot do; centralised monitoring is co-ordinated to underpin SLA Management.

In addition with this scenario, the federator provides added value services to the facility providers (e.g. handling payments and monitoring of SLAs), so these need to be described in contracts or SLAs, as well as the information to be provided to the federator. Hence, an important relationship in this scenario is the provisioning of usage information to the federator that can be used to determine the bill for the experimenters.

**Table 7: Role analysis of Fed4FIRE federation scenario**

| Service | Co-ordination | Reasoning |
|---|---|---|
| **Authentication** | Co-ordinated | Central authentication services can minimize the management of security across the federation and simplify the access to protected resources for the experimenter |
| **Resource Discovery** | Co-ordinated | A central directory of resources offers significant value to help experimenter discovery what is both possible and available across the entire federation |
| **Resource Reservation** | Co-ordinated | Federator can observe available resources across federation that match requirements and allocate reservations accordingly. Optimize the service for both experimenter and testbeds |
| **Monitoring (SLAs)** | Co-ordinated | The federator collects usage information from the testbeds, which can be used to build systems to manage SLAs at the federation level (reputation system) and be used for first level support. |
| **Documentation** | Co-ordinated | Centralized up-to-date data collection of procedures is an important role for the federator towards experimenters |
| **Resource provisioning, and experimental control and measurement** | Uncoordinated | Once reserved experimenters can access the testbeds directly, there is little need to centralize this activity, which would increase the complexity and management of the federation with few benefits. |

Based upon the description above, an evaluation was made of the required efforts it would take to operate all service components. An overview of the results is shown in Figure 6, split up between costs for the federator and each testbed, and indication of first time investment and yearly required manpower (expressed in FTE). We considered two cases with options for first level support (experiment support) and portal (main entry point for the federation), each with a minimal and advance offering. As shown, the second case will demand a larger number of FTE (mostly due to the portal development with advanced functionality). At least 3 FTE should be allocated centrally to the technical operations of the federation, and 1,5 FTE per facility provider. The latter is not additional compared to the current work, but is in line with current and future developments. Looking at the required hardware for the federator. in both cases this is manageable, as the biggest infrastructure lies with the facility providers to offer the resources for experimentation.

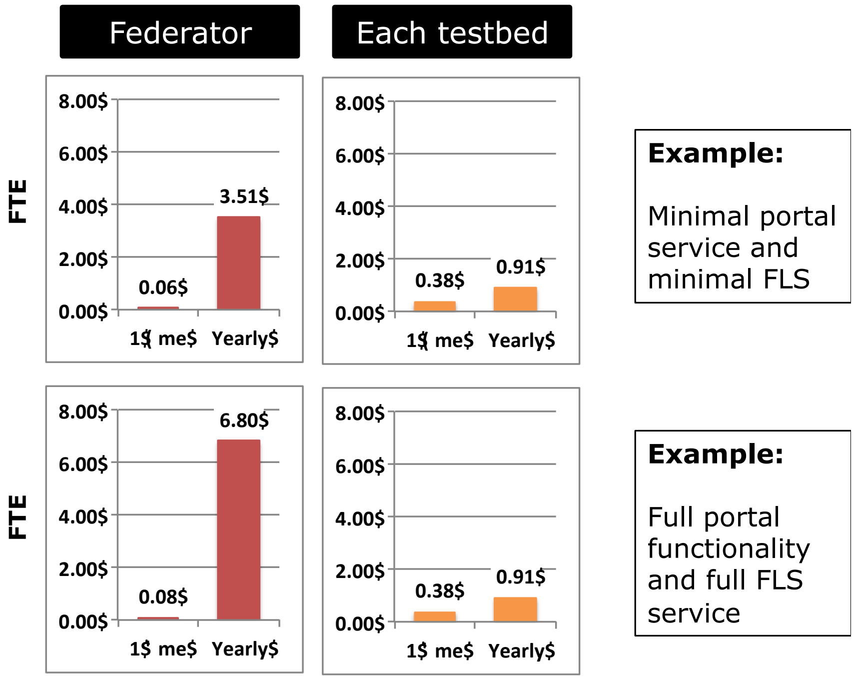


**Figure 6: Plausible business scenario: FTE breakdown**

Considering how to keep this sustainable, a way has to be found to keep this all organized and financed (e.g. by a financial contribution from the testbeds, offering software components or personnel in kind for keeping the components up and running, and updated, requesting subsidies from (European or national) funding agencies, request experimenters to contribute, etc. A clear governance structure must be formed in order to sustain the federation in the long run and responsibilities should be clear. This is part of ongoing work within the project.

# 6. Conclusions

The growing complexity of the Future Internet landscape has driven the need for large-scale federations of experimental testbeds that supports the next generation of research and experimentation. However, such facilities are typically difficult to sustain in the long term, particularly in the transition from a publically funded development to a self-sustaining operation. Fed4FIRE is a cross-domain federation of Future Internet testbeds that seeks to lower the barrier to complex experimentation. It can be summarized as “a federation of testbed facilities is a collection of multiple independent testbeds that can be coordinated in different ways for the creation of rich, multi-functional environments for testing and experimentation; and has clear benefits for its main stakeholders - experimenters, and facility providers.”

This paper explored the different steps within the Fed4FIRE sustainability plan. We indicated the different aspects of our value proposition, to experimenters as well as to testbeds, based upon a requirement analysis from open call information. We listed the potential service portfolio that could be offered and operated by the federator. A service management approach based upon the FitSM framework was followed, presenting the potential core and supplementary services, their components and allocated configuration items. This study was used as basis for defining business scenarios with a specific service offering from federator point of view, considering of course the interaction with and potential benefits for the different testbeds. A plausible scenario was elaborated with an initial qualitatively and quantitative evaluation. This study will be extended in the upcoming months with more focus on the authority and organization of the future federation.

## Acknowledgement

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## References

[1] FIRE, http://www.ict-fire.eu/
[2] BonFIRE project, http://www.bonfire-project.eu/
[3] Helux Nebula project, http://helix-nebula.eu/
[4] CREW project, http://www.crew-project.eu/
[5] OFELIA project, http://www.fp7-ofelia.eu/
[6] Fed4FIRE project, http://www.fed4fire.eu/
[7] N. Moran and M. Loy, "Revenue, Recession, Reliance: Revisiting the SCA/Ithaka S+R Case Studies in Sustainability," JISC Strategic Content Alliance, 2012.
[8] R. Metcalfe, "Sustainability Study: A case study review of open source sustainability models," Joint Information Systems Committee (JISC), Oxford, April 2007.
[9] J. Van Ooteghem, et al., "First sustainability plan", Fed4FIRE Deliverable 2.3, published 31/07/2013
[10] XiPi project, http://www.xipi.eu/
[11] PlanetLab Europe, http://www.planet-lab.eu/
[12] EC H2020 Work Programme 2014-2014, published November 2013, http://ec.europa.eu/research/participants/portal/doc/call/h2020/common/1587758-05i._ict_wp_2014-2015_en.pdf.
[13] FitSM standard family, http://www.fedsm.eu/fitsm
[14] W. Vandenberghe, et al., "Architecture for the heterogeneous federation of Future Internet experimentation facilities", Future Network and Mobile Summit, Lisboa, July 2013, pp. 1-11.
[15] T. Wauters, et al., "Federation of Internet experimentation facilities: architecture and implementation", Proceeding of the EUCNC 2014 conference, June 23-36, Bologna, Italy.
[16] FedSM project, http://www.fedsm.eu/
[17] FedSM, 2012, Owen Appleton, "Deliverable D3.1 - Business models for Federated e-Infrastructure", available online: http://www.fedsm.eu/sites/default/files/FedSM-D3.1-Business_models-v1.0.pdf